Remote Sensing in the 21st Century: Economic and Environmental Applications, Casanova (ed.)
© 2000 Balkema, Rotterdam, ISBN 90 5809 096 5

An automatic method to calibrate Meteosat visible images

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ABSTRACT: A method is described for the automatic calibration of the successive operational Meteosat sensors in the visible range since 1985. The autocalibration method is based on a statistical analysis of the images. This approach does not require any information about atmospheric and surface parameters. As a starting point, the absolute vicarious calibration for only one image in the whole time-series is needed, which can be provided by previous published works. Our results are fully consistent with previous studies. Several tests have been performed to validate the method and check its robustness and reliability.

1 INTRODUCTION

For climatological purposes and for any analysis of a time-series, images from satellite should be well-calibrated with respect to each other, in order to ensure that any variation in time is due to change in the signal coming from the observed target, and not from a change in calibration of the observing system. The Earth viewing calibration approach has been recently developed as a backup solution to the possible failure or unreliability of on-board calibration devices. It is based on the knowledge of physical characteristics of some Earth phenomena as well as upon the processing of the digital imagery flowing down from the sensor itself (see e.g., Köpke 1982, 1983; Frouin, Gautier 1987).

Several techniques have been proposed to solve this calibration problem and have been applied to different types of sensors, either for sun-synchronous satellites (e.g. Holben *et al.* 1990) as for geostationary satellites (e.g., Köpke 1982). In the following, we are interested in calibrating the visible channels of geostationary meteorological satellites, and more precisely of the Meteosat satellite-series. Because these satellites have no onboard calibration system, added to the lack of prelaunch calibration, an absolute calibration of the radiometer in orbit for the VIS channel has to be performed to allow for accurate radiance measurements.

2 BACKGROUND

Assuming a linear response of the sensor, the relationship between the emerging radiance from the atmosphere and measured by the sensor, L_{sat}, and the numerical count, NC, is:

$$L_{sat} = \alpha \, (NC - NC0) \quad (1)$$

where α is the calibration coefficient (in $Wm^{-2}sr^{-1}NC^{-1}$) and NC0 is the offset numerical count of the calibration.

Several authors have proposed a method for the calibration of Meteosat data (see a review in Lefèvre *et al.*, 1999). From an operational point of view, standing from the user side, these methods, though accurate, suffer from some drawbacks. The method of Moulin *et al.* (1996) is the most attractive but we found it rather difficult to implement in an operational chain because of:

- the need of radiative transfer computations with a detailed numerical code *i.e.* the knowledge of atmospheric (water vapour, ozone, aerosol optical properties) and surface parameters (e.g., temperature);
- the need of a first test to extract cloud-free pixels from the database of images to create a 12-year dataset of clear sky, 5-day averaged, numeric counts for selected targets (4 targets chosen in desert areas).

Accordingly, we have looked for a method which can be routinely operated in quasi-real time without external inputs. An empirical approach was adopted which makes use of statistical quantities that can be extracted from each image, following the tracks of Asmami, Wald (1993) and Wald (1998) for the AVHRR instruments. Such methods do not have the beauty of methods explicitly simulating the radiative transfer, but they are presently as accurate as the others, far more simple to perform, even in real time, and far more easy to implement.

A new method, called the autocalibration method, has been devised and tested. Actually this method can only perform the calibration of an image relative to another. It follows that to calibrate a series of images, the procedure is the following:

1 use a calibration function found in the literature, and corresponding to a day, noted t_0
2 calibrate the image corresponding to that day (called hereafter the reference image) using Equation 1
3 perform the autocalibration method to calibrate all the other images relative to the reference one.

The first two steps are performed only once.

3 THE METEOSAT SENSORS – THE IMAGES

The Meteosat program, operated by the European Space Agency (ESA) started in 1977. The VIS data used for the calibration were provided by Eumetsat (Darmstadt, Germany), the European organisation for the exploitation of the Meteosat system and distributor of the images. For the study, a special set of Meteosat data was used, called ISCCP-B2. This set of images has been set up in the framework of the International Satellite Cloud Climatology Project (ISCCP), part of the World Climate Research Program (WCRP). This set is derived from the operational Meteosat images, in both visible and thermal infrared bands by a reduction of the number of pixels. The remaining pixels still bear their original values after they have been brought to the spatial size of the infra-red images (5 km at nadir).

Our dataset covers all years since 1985. For that period, five Meteosat satellites and sensors have been operated, at different gain levels. The various Meteosat sensors have different sensitivities due to their difference in the spectral band. Each of the spectral channels can be operated at one of 16 different gain levels. These gain levels are used to obtain the optimum dynamic range for each spectral channel and are adjusted as required (Eumetsat, 1996). These changes in gain affect the sensitivity of a given sensor, and are to be compensated by an adjustment of the operational calibration coefficient.

The spectral response of each VIS channel of each sensor is taken from Eumetsat (1996) and other authors. The overall spectral response of a given radiometer channel is a combination of the optical transmission of the entire optical system and the detector response. The spectral responses S_λ , λ being the wavelenght, have varying shapes, with a maximum transmission between 600 nm and 900 nm. The operational Meteosat satellites have in common a spectral channel at about 700 nm, near the peak of the solar spectrum. Meteosat-1 and -2 have similar spectral response, and are less sensitive than the other sensors below 600 nm. On the opposite, Meteosat-4 and -5 are more sensitive in the first half of the bandwidth. Meteosat-5 is less sensitive than Meteosat-2, -3 and -4 at wavelengths greater than 800 nm.

O'Mongain *et al.* (1983) have emphasised that the calibration depends on the shape of the spectral sensitivity curve of the radiometer. For broad band channels like that of Meteosat sensors, the knowledge of the spectral distribution of the input radiance is mandatory. Values of solar spectral irradiances incident at the top of the atmosphere $I_{0\lambda}$ are those of Neckel, Labs (1984). Then the spectral distribution corresponding to each Meteosat sensor, that is the product of the solar spectral constant with the sensor response (*i.e.* $I_{0\lambda}$ S_λ in Wm^{-2}) is computed, as well as the total irradiance in the VIS channel for the various Meteosat sensors (*i.e.* integrated from 0.3 µm to 1.1 µm, $\int_{0.3}^{1.1} I_{0\lambda} S_\lambda d\lambda$). More energy flux is available for Meteosat-3, -4 and -5 because the corresponding bandwidths are larger than those of the first two Meteosat sensors.

The effective radiance, L_{sat} (in $Wm^{-2}sr^{-1}$), is the integral of the radiance emerging upward from the atmosphere measured by Meteosat VIS channel, L_λ (in $Wm^{-2}sr^{-1}mm^{-1}$), weighted by its spectral response, S_λ, and is defined as:

$$L_{sat} = \int_0^\infty L_\lambda S_\lambda d\lambda \qquad (2)$$

where L_λ is the spectral radiance at the entrance of the satellite sensor. The spectral radiance L_λ depends on the viewing geometry, *i.e.*, on the solar zenithal angle, on the satellite zenithal (viewing) angle and on the relative azimuthal angle. It is also dependent on the spectral irradiance of the solar constant outside the atmosphere, $I_{0\lambda}$, and on the spectral optical properties of atmosphere and surface. L_{sat} is digitised by the electronics of the sensor onboard the satellite.

A calibration function is often a linear function, with a good approximation (see Eq. 1). It links digital count to reflectances (or albedo) in the visible range. Therefore, two points are necessary to determine this linear function. The farther these points, the more accurate the determination of the straight line. Accordingly, calibration is made by observing a dark target and a bright one. For the visible range, there is no internal calibration. The calibration function has been set prior to launch, and is used throughout the life of the sensor. The pre-flight calibrations are subject to change due to launch constraints and the hostile environment of the sensor: outgasing, deterioration in the optronic system, variation in the spectral filter characteristics, ... They induce changes in the calibration function which are unknown, but should be known for a reliable processing of the images in the visible range.

4 THE AUTOCALIBRATION METHOD

The autocalibration method is based on the analysis of two quantities which are constant in radiance over the time-series. The work of Moulin *et al.* helped us in selecting several time periods during which the calibration parameters were fairly constant. Using our experience gained with the AVHRR sensor, we have searched during these periods, statistical parameters using the fact that in the entire field of view of the Meteosat sensor, the mixed presence of land, ocean, and clouds of different reflectivity over approximately one third of the Earth, whatever the day and time of the year, may lead to the preservation of such statistical quantities with time. In an empirical way, we selected three parameters which are the numerical counts corresponding to a dark target, and to the percentiles 5 % and 80 % of the histogram of the mid-day image. These numerical counts vary in time according to the Meteosat sensor and the date of viewing, but the two quantities that are derived in radiances (and defined in the following) were found constant for the test periods. The analysis of the whole time-series with respect to the calibration proposed by Moulin *et al.* (1996) demonstrated that any drift in these quantities reflect a drift in the calibration of the Meteosat sensor.

For each day t for which images are to be calibrated, the three parameters are computed. The numerical count for the dark target, $NC_{t_{dark}}$, is computed using the early image at 0530 UT (slot 11). At that time, most of the portion of the Earth viewed by Meteosat is still in the night. The histogram is built for that night-time part of the image and the first mode gives $NC_{t_{dark}}$.

Then the daytime image at 1130 UT (slot 24) is considered. Only pixels which numerical count is greater than $NC_{t_{dark}}$ are taken into account and the histogram is computed. Percentiles 5 % and 80 % are extracted and this provides the corresponding numerical counts NC_{t5} and NC_{t80}; we recall that NC_{t5} (resp. NC_{t80}) represents the numerical count for which 5 percent (resp. 80 percent) of the surface of the cumulative histogram is reached (percentile 5 %, resp. 80 %). These parameters vary along the time, from one Meteosat sensor to another, from one gain to another for the same sensor, and also from day to day for the same sensor and same gain (Figure 1).

For the day t_0, these three parameters: $NC_{to_{dark}}$, NC_{to5} and Nc_{to80}, can be converted into radiances: $L_{to_{dark}}$, L_{to5} and L_{to80} by the means of Eq. 1:

$$L_t = \alpha_t (NC_t - NC0_t) \tag{3}$$

$$L_{t_{dark}} = \alpha_t (NC_{t_{dark}} - NC0_t) \tag{4}$$

$$L_{to_{dark}} = \alpha_{to} (NC_{to_{dark}} - NC0_{to}) \tag{5}$$

$$L_{to5} = \alpha_{to} (NC_{to5} - NC0_{to}) \tag{6}$$

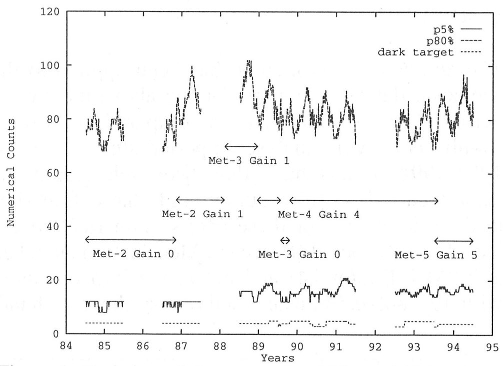

Figure 1. Variation of the percentiles NC_{t5} and NC_{t80} (noted here p5% and p80%) and of the dark target $NC_{t_{dark}}$ for Meteosat VIS channel at 1130 UT and from January 1, 1985 to December 31, 1994. The satellite sensor and the gain are also reported.

$$L_{to80} = \alpha_{to} (Nc_{to80} - NC0_{to}) \tag{7}$$

which leads to :

$$\alpha_{to} = \frac{(L_{to\,80} - L_{to5})}{(NC_{to\,80} - NC_{to\,5})} \tag{8}$$

$$\alpha_t = \frac{(L_{t\,80} - L_{t5})}{(NC_{t\,80} - NC_{t\,5})} \tag{9}$$

$$NCO_t = NC_{t\,dark} - L_{t\,dark}\frac{1}{\alpha_t} \tag{10}$$

The two following quantities are constant with time:

$$\frac{L_{to_{dark}}}{I_{to}} = \frac{L_{t_{dark}}}{I_t} \tag{11}$$

$$\frac{\left(L_{to_{80}} - L_{to_5}\right)}{I_{to}} = \frac{\left(L_{t_{80}} - L_{t_5}\right)}{I_t} \tag{12}$$

where I_t and I_{to} are the incoming irradiances in the VIS radiometer at days t and t_0. They are equal to the total irradiances for the VIS sensors under concern above-mentioned, multiplied by the correction of the astronomical distance from the Sun to the Earth for the days t or t_0. This ratioing also accommodates for the changes in sensor. After the substitution of Eqs. 9, 10, 11 and 12 into Eq. 3, and some mathematical handling, the radiance L_t at any time t and for each numerical count NC_t is:

$$L_t = \frac{(L_{to80} - L_{to5})}{(NC_{t80} - NC_{t5})}\frac{I_t}{I_{to}}\left(NC_t - NC_{t_{dark}}\right) + L_{to_{dark}}\frac{I_t}{I_{to}} \tag{13}$$

5 RESULTS

The autocalibration method has been applied to the Meteosat dataset spanning for the above-mentioned period. The results have been compared to those of Moulin *et al.* who analysed a period similar to ours: 1983-1994. Pixels have thus been selected in the same locations as these authors did, that is four sites in desertic areas. For these pixels, numerical counts have been extracted from each Meteosat image taken at 1130 UT (slot 24) and converted into radiances with the autocalibration method on the one hand,

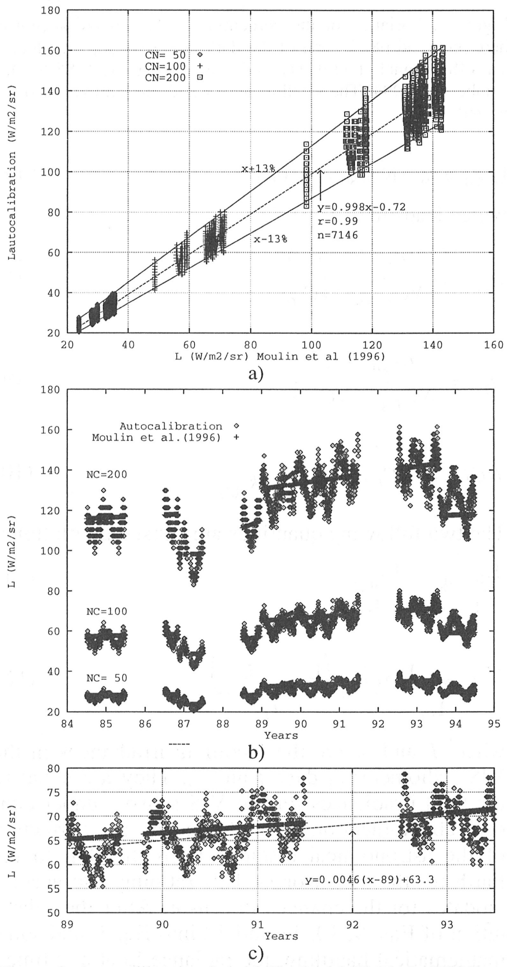

Figure 2. Autocalibration is initialised with Köpke's (1983) coefficients on 01/01/89. Radiance calculations are made for numerical counts NC 50, 100 and 200. ***a)*** Comparison with Moulin *et al.* results. ***b)*** Radiances for both methods. The juxtaposition of the crosses "+" makes the Moulin *et al.* results appearing as thick lines. ***c)*** Magnification of the drawing of ***b)*** for NC=100 during Meteosat-4 period. Also shown is the regression line for the autocalibration results as a function of the year *x* (in floating values).

and with the coefficients published by Moulin *et al.* on the other hand.

As said above, the autocalibration method requires an absolute calibration for the radiance on one image at least. We have tested several dates for the day t_0 with different coefficients of calibration taken from known calibration coefficients calculated by vicarious calibration (Moulin *et al.*, 1996) for June 1983 to December 1994, and from aircraft experiment: Köpke (1983) for the end of 1981, or Kriebel, Amann (1993) for August - September 1989.

All our results are consistent with Moulin *et al.* (1996) results for the same time series from 1985 to 1994. The correlogram between both sets of results shows a slope close to 1 and a correlation coefficient of 0.91. This coefficient is 0.95 for the four sites used by Moulin *et al.*

From the analysis of the time-series, it is obvious that whatever the method is, the fluctuation in calibration within a year is quite large: approx. $15\ W\ m^{-2}\ sr^{-1}$ in radiance for NC = 100, that is approx. 23 percent of the mean radiance. It follows that a formula based upon a linear regression such as that proposed by Moulin *et al.* and others does not provide the best results, as demonstrated by the low correlation coefficient between the proposed formula and the samples (0.51). We conclude that calibration coefficients should be assessed on a daily basis preferrably.

Figure 2 displays the results of one of the multiple tests. The initialisation is made with the coefficients of Köpke (1983) set up for January 1, 1989. The autocalibration coefficients as well as the Moulin *et al.* Coefficients are applied to the digital counts NC 50, 100 and 200. The relative rms error claimed by Moulin *et al.* is 13 %, and is reported in this figure.

Figure 3 displays the results for the initialisation made with the coefficients of Kriebel, Amman (1993) set up for September 9, 1989, and for the Tunisian desert.

6 CONCLUSION

A method of autocalibration of Meteosat B2 VIS channel has been developed, based on the analysis of changes in statistical quantities extracted in each image.

We have tested different dates for the absolute reference, as well as different known calibration coefficients calculated from vicarious calibration and from aircraft experiment. All our results are consistent with Moulin *et al.* (1996) results for the same time series from 1985 to 1994. It was also shown that a calibration law based upon a linear function of the day is not providing the best results, though very easy to handle. The autocalibration method performs similarly or better than such formulae. Several tests

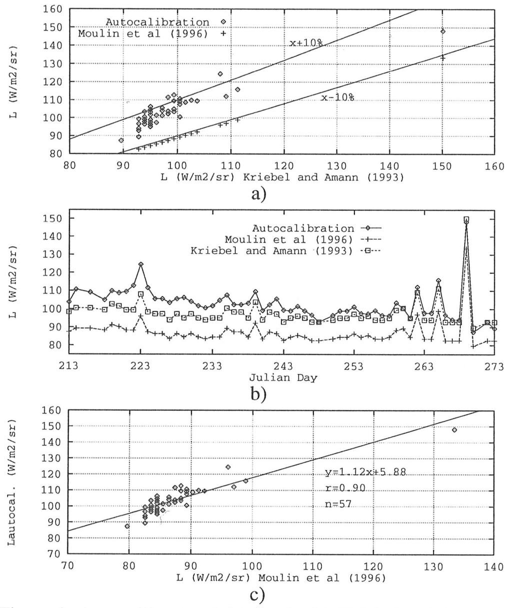

Figure 3. Autocalibration initialised with Kriebel and Amann's (1993) coefficients on 05/09/89 for the Tunisian desert. The radiances are computed for a rectangular shaped sensitivity of the radiometer during August-September 1989. ***a)*** Comparison between autocalibration and Kriebel and Amann. ***b)*** Radiances from 01/08/89 to 30/09/89 (Meteosat-4) for the three calibration laws. ***c)*** Comparison between autocalibration and Moulin *et al.*

have been performed to validate the method and check its robustness and reliability.

Its main advantage is its very easy implementation as it does not require any radiative transfer procedure nor any specific targets to be extracted like in ocean or desert. One single date for the absolute calibration is sufficient, and moreover this single date can be any day of the time series. The present approach provides reliable calibration without external knowledge and/or human operator. It makes it simple to calibrate rapidly a large time series of images.

The autocalibration method can be applied to Meteosat images acquired before 1985 and after 1994. The authors think that it should be also applicable to other geostationary satellites having spectral bands similar to Meteosat, such as GOMS, GMS, Insat, and the first GOES series, but no check has been performed so far.

A work is undertaken at Ecole des Mines de Paris for the calibration of the Meteosat images, starting January 1985 up to now. The calibration coefficients should be made available on the Web site: www-helioserve.cma.fr.

ACKNOWLEDGEMENTS

The help of the Joint Research Centre (Ispra, Italy) is acknowledged: it indirectly initiated that study which also benefited from the collection of several years of Meteosat images made under a contract with JRC within the MARS programme, and held at Ecole des Mines de Paris. Very fruitful discussions have been held with Eumetsat on several aspects: we particularly thank Richard Francis and the archives Department MARF.

REFERENCES

Asmami, M. & L. Wald 1993. A method for an accurate on-flight calibration of AVHRR data for vegetation index calculation. In *Remote sensing for monitoring the changing environment of Europe*: 53-57. Rotterdam: Balkema.

Eumetsat 1996. Annex to the Meteosat-5 calibration report. Meteorological Products Extraction Facility (MPEF), March 1996. Eumetsat, Darmstadt, Germany, 25 pp.

Frouin, R. & C. Gautier 1987. Calibration of NOAA-7 AVHRR, GOES-5 and GOES-6 VISSR/VAS solar channels. *Remote Sensing of Environment* 22 (1): 73-101.

Köpke, P. 1982. Vicarious satellite calibration in the solar spectral range by means of calculated radiances and its application to Meteosat. *J. of Appl. Optics* 21(15): 2845-2854.

Köpke, P. 1983. Calibration of the Vis-channel of Meteosat-2. *Advances in Space Research* 2(6): 93-96.

Kriebel, K. T. & V. Amann 1993. Vicarious calibration of the Meteosat visible channel. *Journal of Atmospheric and Oceanic Technology* 10(2): 225-232.

Lefèvre, M., O. Bauer, A. Iehle, L. Wald 1999. An automatic method for the calibration of time-series of Meteosat images. To be published by *Int J. of Remote Sensing*.

Moulin, C., C.E. Lambert, J. Poitou & F. Dulac 1996. Long term calibration of the Meteosat solar (VIS) channel using desert and ocean targets. *International Journal of Remote Sensing*, 17(6): 1183-1200.

Neckel, H. & D. Labs 1984. The solar radiation between 3300 and 12500 Å. *Solar Physics* 90: 205-258.

O'Mongain, E., M. Goodman, M. Reynolds & C.B. Connor 1983. High-accuracy calibration of optical imaging instruments in space. *ESA Journal*, 7(3): 299-309.

Wald, L. 1998. In-flight interband calibration of the AVHRR data by a cloud-viewing technique. In P. Gudmansen (ed.) *Future Trends in Remote Sensing*: 453-459. Rotterdam: Balkema.